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Comparing Acquisition Strategies: Maintenance-Free Operating Period vs. Traditional Logistics Support

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14. ABSTRACT

For more than a decade, the U.S. Navy has been modernizing many of its software intensive National Security Systems (NSS) using an Open Architecture (OA) approach that leverages capable and reliable commercial off-the-shelf (COTS) technologies and modern, agile software development practices. The focus of the Naval Open Architecture strategy has been to field affordable and superior capabilities more rapidly at reduced costs. NSS and information technology (IT) system upgrades are now routinely accomplished using COTS, proving that the U.S. Navy has achieved measureable success in this area. But this progress has not improved the environment of life cycle cost savings and system sustainment. The Integrated Logistics Support (ILS) elements of most acquisition programs are not taking full advantage of industry best practices that are robust and mature for life cycle affordability and sustainment. There is great cost savings potential in this area as the cost of ownership of a system aboard a ship over its life cycle for repair and maintenance far exceeds the Navy?s initial investment in design and production. This paper gives an overview of Maintenance Free Operating Period (MFOP) pilot implementations that have been deployed twice aboard Navy ships. It will describe a fundamentally new system sustainment approach and acquisition techniques, which show how MFOP is a viable alternative to traditional ILS life cycle methods. Finally we will argue that system designs using the MFOP approach are generally superior in terms of cost, performance, and resource management.

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Preface & Acknowledgements

During his internship with the Graduate School of Business & Public Policy in June 2010, U.S. Air Force Academy Cadet Chase Lane surveyed the activities of the Naval Postgraduate School's Acquisition Research Program in its first seven years. The sheer volume of research products—almost 600 published papers (e.g., technical reports, journal articles, theses)—indicates the extent to which the depth and breadth of acquisition research has increased during these years. Over 300 authors contributed to these works, which means that the pool of those who have had significant intellectual engagement with acquisition issues has increased substantially. The broad range of research topics includes acquisition reform, defense industry, fielding, contracting, interoperability, organizational behavior, risk management, cost estimating, and many others. Approaches range from conceptual and exploratory studies to develop propositions about various aspects of acquisition, to applied and statistical analyses to test specific hypotheses. Methodologies include case studies, modeling, surveys, and experiments. On the whole, such findings make us both grateful for the ARP's progress to date, and hopeful that this progress in research will lead to substantive improvements in the DoD's acquisition outcomes.

As pragmatists, we of course recognize that such change can only occur to the extent that the potential knowledge wrapped up in these products is put to use and tested to determine its value. We take seriously the pernicious effects of the so-called "theory–practice" gap, which would separate the acquisition scholar from the acquisition practitioner, and relegate the scholar's work to mere academic "shelfware." Some design features of our program that we believe help avoid these effects include the following: connecting researchers with practitioners on specific projects; requiring researchers to brief sponsors on project findings as a condition of funding award; "pushing" potentially high-impact research reports (e.g., via overnight shipping) to selected practitioners and policy-makers; and most notably, sponsoring this symposium, which we craft intentionally as an opportunity for fruitful, lasting connections between scholars and practitioners.

A former Defense Acquisition Executive, responding to a comment that academic research was not generally useful in acquisition practice, opined, "That's not their [the academics'] problem—it's ours [the practitioners']. They can only perform research; it's up to us to use it." While we certainly agree with this sentiment, we also recognize that any research, however theoretical, must point to some termination in action; academics have a responsibility to make their work intelligible to practitioners. Thus we continue to seek projects that both comport with solid standards of scholarship, and address relevant acquisition issues. These years of experience have shown us the difficulty in attempting to balance these two objectives, but we are convinced that the attempt is absolutely essential if any real improvement is to be realized.

We gratefully acknowledge the ongoing support and leadership of our sponsors, whose foresight and vision have assured the continuing success of the Acquisition Research Program:

- Office of the Under Secretary of Defense (Acquisition, Technology & Logistics)
- Program Executive Officer SHIPS
- Commander, Naval Sea Systems Command
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- Program Manager, Airborne, Maritime and Fixed Station Joint Tactical Radio System

- Program Executive Officer Integrated Warfare Systems
- Office of the Assistant Secretary of the Air Force (Acquisition)
- Office of the Assistant Secretary of the Army (Acquisition, Logistics, & Technology)
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- Office of Procurement and Assistance Management Headquarters, Department of Energy

We also thank the Naval Postgraduate School Foundation and acknowledge its generous contributions in support of this Symposium.

James B. Greene, Jr.
Rear Admiral, U.S. Navy (Ret.)

Keith F. Snider, PhD
Associate Professor

Panel 25 – Logistics Enablers for Enhanced Acquisition Outcomes

Thursday, May 12, 2011	
3:30 p.m. – 5:00 p.m.	**Chair: Lorna B. Estep,** Deputy Director of Logistics, Air Force Material Command ***Maximizing Effectiveness Using a Flexible Inventory*** Manbir Sodhi, University of Rhode Island, and James Ferguson, Marie Bussiere, and Betty Jester, USN ***Identifying and Managing Manufacturing and Sustainment Supply Chain Risks*** Nancy Moore, Elvira Loredo, and Amy Cox, RAND Corporation ***Comparing Acquisition Strategies: Maintenance-Free Operating Period vs. Traditional Logistics Support*** Nickolas H. Guertin, Open Architecture, PEO IWS, and Paul Bruhns, ManTech International Corporation

Lorna B. Estep—Deputy Director of Logistics, Directorate of Logistics and Sustainment, Headquarters Air Force Materiel Command, Wright-Patterson Air Force Base, OH. Ms. Estep is a member of the Senior Executive Service. She is responsible for the Materiel Support Division of the Supply Management Activity Group, a stock fund with annual sales of $7 billion. She directs a wide range of logistics services in support of Air Force managed spare parts, to include transformation programs, requirements determination, budgeting, acquisition, provisioning, cataloging, distribution and data management policy. She also provides supply chain management policy, guidance and direction in support of headquarters, air logistics centers, and U.S. Air Force worldwide customers.

Estep started her career as a Navy logistics management intern. She has directed the Joint Center for Flexible Computer Integrated Manufacturing, was the first program manager for Rapid Acquisition of Manufactured Parts, and has served as Technical Director of Information Technology Initiatives at the Naval Supply Systems Command. In these positions, she has developed logistics programs for the Department of Defense, implemented one of the first integrated and agile data-driven manufacturing systems, and directed the development of complex technical data systems for the Navy.

Comparing Acquisition Strategies: Maintenance-Free Operating Period vs. Traditional Logistics Support

Nickolas H. Guertin—Director, Naval Open Architecture Enterprise Team (OAET) PEO, Integrated Warfare Systems–IWS-7. Mr. Guertin received a BS in mechanical engineering from the University of Washington and an MBA from Bryant University. He is a registered Professional Engineer and is Defense Acquisition Workforce Improvement Act (DAWIA) certified in Program Management and Systems Planning Research Development and Engineering. Mr. Guertin enlisted in the U.S. Navy as a submarine nuclear power plant electrical operator. After six years on active duty, during which time he served aboard USS *Thomas Jefferson* and USS *Silversides*, he joined the Navy Reserve. Following completion of his undergraduate degree, he accepted a USNR commission as an Engineering Duty Officer, specializing in ship construction and repair. He has subsequently retired from the Navy Reserve, having completed a range of engineering duty ship repair and construction assignments leading up to command of a ship repair team. Mr. Guertin began his civil service career at Puget Sound Naval Shipyard in nuclear propulsion plan testing. He then went on to Naval Undersea Warfare Center Keyport as a heavyweight torpedo depot engineer. Mr. Guertin then shifted to combat systems as the Sonar Participating Manager representative for Trident Command and Control System testing. Mr. Guertin's experience in Open Architected systems includes being on the team that started the Acoustic Rapid Commercial Off The Shelf (COTS) Insertion (A-RCI) program, the Assistant Program Manager for the Total Ship Monitoring System, and duties as the chief engineer for submarine combat control, which incorporated the business and technical processes established under the A-RCI program. Mr. Guertin currently serves in the Program Executive Office for Integrated Warfare Systems as the Deputy Director for Open Architecture, and leads the transformation to change the business, technical, and cultural practices for how the Navy and Marine Corps buys and builds systems as a coordinated enterprise effort. Mr. Guertin is married to Maria Foderaro-Guertin. They have two children and reside in McLean, VA.

Paul Bruhns

Abstract

For more than a decade, the U.S. Navy has been modernizing many of its software intensive National Security Systems (NSS) using an Open Architecture (OA) approach that leverages capable and reliable commercial off-the-shelf (COTS) technologies and modern, agile software development practices. The focus of the Naval Open Architecture strategy has been to field affordable and superior capabilities more rapidly at reduced costs. NSS and information technology (IT) system upgrades are now routinely accomplished using COTS, proving that the U.S. Navy has achieved measureable success in this area. But this progress has not improved the environment of life cycle cost savings and system sustainment. The Integrated Logistics Support (ILS) elements of most acquisition programs are not taking full advantage of industry best practices that are robust and mature for life cycle affordability and sustainment. There is great cost savings potential in this area, as the cost of ownership of a system aboard a ship over its life cycle for repair and maintenance far exceeds the Navy's initial investment in design and production.

This paper gives an overview of Maintenance Free Operating Period (MFOP) pilot implementations that have been deployed twice aboard Navy ships. It will describe a fundamentally new system sustainment approach and acquisition techniques, which show how MFOP is a viable alternative to traditional ILS life cycle methods. Finally, we will argue that system designs using the MFOP approach are generally superior in terms of cost, performance, and resource management.

Introduction

For more than a decade, the U.S. Navy has been modernizing many of its software intensive National Security Systems (NSS) using an Open Architecture (OA) approach that leverages capable and reliable commercial off-the-shelf (COTS) technologies and modern, agile software development practices. The focus of the Naval Open Architecture strategy has been to field affordable and superior capabilities more rapidly at reduced costs. NSS and information technology (IT) system upgrades are now routinely accomplished using COTS, proving that the U.S. Navy has achieved measureable success in this area. But this progress has not improved the environment of life cycle cost savings and system sustainment. The Integrated Logistics Support (ILS) elements of most acquisition programs are not taking full advantage of industry best practices that are robust and mature for life cycle affordability and sustainment. There is great cost savings potential in this area, as the cost of ownership of a system aboard a ship over its life cycle for repair and maintenance far exceeds the Navy's initial investment in design and production.

This paper gives an overview of Maintenance Free Operating Period (MFOP) pilot implementations that have been deployed twice aboard Navy ships. It will describe a fundamentally new system sustainment approach and acquisition techniques, which show how MFOP is a viable alternative to traditional ILS life cycle methods. Finally, we will argue that system designs using the MFOP approach are generally superior in terms of cost, performance, and resource management.

Why Maintenance Free Operating Periods?

The simple answer is that an OA/MFOP enabled system saves money and provides the warfighter with a product that is better, cheaper, and faster:

1. Better because the MFOP design yields more operational availability to the warfighter.
2. Cheaper because there is less material, infrastructure, and training to provide and manage through the elimination of platform/system level, material support packages.
3. Faster because distance support techniques eliminate delays in supporting fielded products and are available world-wide.

The Maintenance Free Operating Period Defined

The Maintenance Free Operating Period (MFOP) is defined as the specified period of time that a system must be available in support of its required mission, with a specified level of reliability, and with no open cabinet maintenance. Commercially available methods and products support very high probability of system availability, approaching 99% or greater. In general terms, Reliability (of mission time) is stated as follows:

$$R(t) = e^{-t/MTBF},$$

where *t* is the mission time (required MFOP), and *MTBF* is system Mean Time Between Failure under stated conditions.

An MFOP-enabled system is inherently reliable with continuous health monitoring status to provide confidence that the tactical application availability requirement is highly likely to be met. To achieve this, the MFOP system has the following design enablers:

1. Fault Tolerant Design,
2. Data Collection, and
3. Remote Connectivity.

Fault tolerant COTS based designs utilize vendor-supplied Mean Time Between Failure (MTBF) data as a starting point. The system is then constructed based on a reliability block diagram that provides sufficient redundancy to meet the required level of reliability. This accounts for the MTBF levels of the included components. Note that vendor MTBF data is usually provided to users based upon specific conditions, generally a benign laboratory environment.

Open Architecture and the MFOP Evolution

Open Architecture (OA) is a collection of best practices, technical and business, and when combined with a willing corporate culture, can result in a highly effective life cycle strategy in which total cost of ownership is minimized and capabilities to the warfighter are maximized.

The Navy has extended the work of the Modular Open Systems Approach (MOSA) work performed by the DoD's Open Systems Joint Task Force (OSJTF) to more comprehensively achieve the desired goals of open architecture as a part of the Naval Open Architecture (NOA) effort. NOA is defined as the confluence of business and technical practices yielding modular, interoperable systems that adhere to open standards with published interfaces. It is the goal of the Naval Open Architecture effort to "field common, interoperable capabilities more rapidly at reduced costs" (*Updated Naval OA Strategy*, 2008).

The Navy and Marine Corps are incorporating OA into selected new start acquisition or upgrades to existing programs such as Common Afloat Network Enterprise Services (CANES), Submarine Warfare Federated Tactical Systems (SWFTS), Joint Counter-Radio control improvised explosive device Electronic Warfare (JCREW*)*, and others (Fein, 2009).

The following are the core principals of the Open Systems Architecture approach (Guertin & Clements, 2010):

1. Modular designs with loose coupling and high cohesion that allow for independent acquisition of system components;
2. Continuous design disclosure and appropriate use of data rights allowing greater visibility into an unfolding design and flexibility in acquisition of alternatives;
3. Enterprise investment strategies that maximize reuse of system designs and reduce total ownership costs (TOC);
4. Enhanced transparency of system design through open peer reviews;
5. Competition and collaboration through development of alternative solutions and sources;
6. Analysis to determine which components will provide the best return on investment (ROI) to open…i.e., which components will change most often due to technology upgrades or parts obsolescence and have the highest associated cost over the life cycle.

Achievement of these six principles requires an affirmative answer to a fundamental question: Can a qualified third party add, modify, replace, remove, or provide support for a component of a system, based only on openly published and available technical and functional specifications of the component of that system?

OA is ultimately about enabling acquisition choice. When program managers can compete for products and services across a system design, they can establish an environment of continuous competition for the best possible solution at the best possible price.

MFOP Evolution

Since 2005, two MFOP pilots have been conducted on Navy ships:

- **Submarine MFOP Pilot Program.** The AN/BQQ-10 (a.k.a., Acoustic Rapid COTS Insertion, or ARCI) submarine tactical sonar system is the premier example program for an Open Architecture (OA) in the Navy. This program pioneered OA in the Navy/Marine Corps. In 2005, four submarines were augmented with additional embedded servers and additional design elements to ensure a 90-day MFOP period for tactical software availability within the MFOP boundary. The rest of the system was managed using the traditional ILS support system. Five years later, the tools and techniques now able to tackle the full range of technical challenges that confronted the earlier attempts have been greatly improved by the commercial market computing industry.
- **Surface Ship MFOP Demonstration.** This was conducted in 2010 as a comprehensive OA/MFOP demonstration aboard USS *Iwo Jima* (LHD 7). The demonstration exercised the Navy's evolving concepts for risk reduction and cost savings, as well as exploring the full extent of the MFOP concept. This demonstration relied on reuse of two different operational software assets, one from the Navy's Software Hardware Asset Reuse Enterprise (SHARE) repository, and the other through program/domain awareness. These Navy-funded designs were combined with commercially available management capabilities and re-hosted on a highly reliable commercial blade center with embedded spares that was designed for the entire system boundary. In this demonstration, the system MFOP period was doubled to 180 days, and the certified support package provided in the temporary installation (TEMPALT) had zero maintenance support items provided to the ship.

Case Study: The Surface Ship OA/MFOP Demonstration

Requirements and Approach

The object of the Surface Ship OA/MFOP Proof of Concept demonstration was to develop a scalable and extensible demonstration system that would provide a greater than 99% probability for a tactical capability under test. Success would be measured by completing a deployment on a combat ship of 180 days with no open cabinet maintenance, while eliminating the traditional shipboard maintenance support package. All design decisions associated with the implementation methods were targeted for an NSS of scale and complexity, so that these lessons and designs could be used for large-scale programs such as PEO C4I's CANES, PEO SUB's SWFTS, PEO LMW's Littoral Combat Ship Mission Module program, and PEO IWS's AEGIS, among others.

For control purposes, the system required an operational capability from which to measure system availability and design for reliability. The Common Network Interface (CNI) software application, originally contracted by PEO IWS 6 for Amphibious Assault Ships and developed by GD-AIS, was selected. The specific version of CNI used in the demonstration was selected due to its availability in SHARE repository and the willingness of the originating program office to support the demonstration. A suitable hardware platform, that is, one that would be typical of, and extensible to, a shipboard tactical information system, was then configured to ensure CNI would be operationally available for the stated mission time.

OA/MFOP Demonstration System Design

Three particular design features were used in the surface ship demonstration system (see Figure 1):

- **Fault Tolerance.** The hardware platform was made fault tolerant by adding and embedding redundancy based on the hardware vendor's supplied component MTBF data, and adding a method for controlling spare resources (failover).
- **Data Capture and Collection.** All components, including power and cooling devices, were monitored, either through built-in Simple Network Management Protocol (SNMP) message traps, or more sophisticated software agents running in data servers. This data was continuously collected for online assessment and post mission analyses.
- **Remote Connectivity.** The system was connected to SIPRNET. The purpose of this link was to collect reliability performance information for online assessment, and to allow subject-matter experts (SMEs) ashore to restore system operation in the event of a software failure.

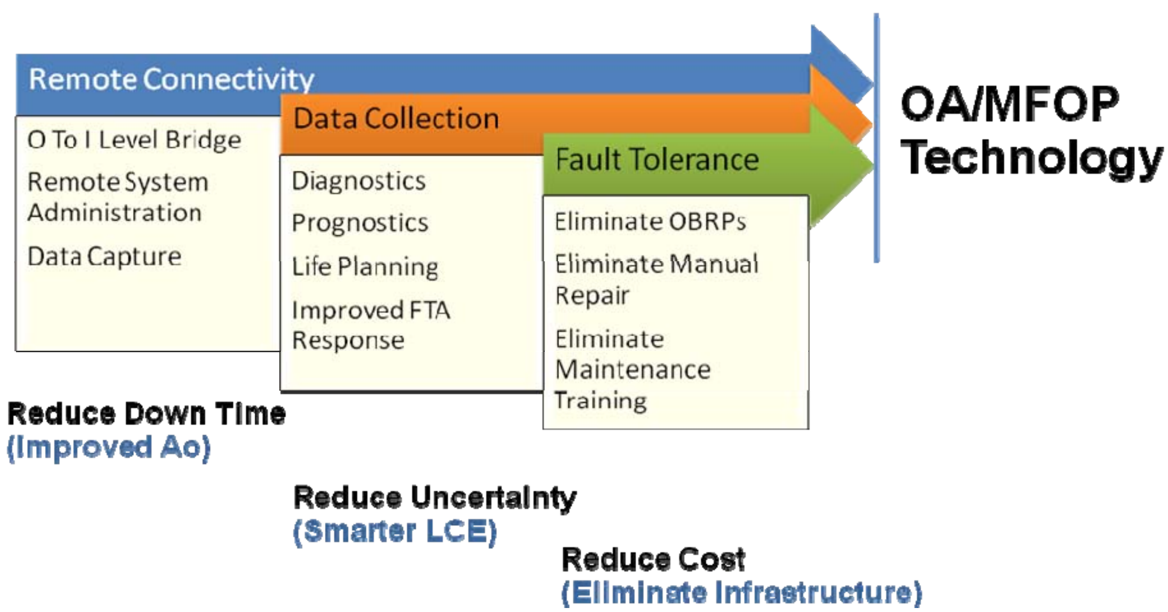

Figure 1. OA/MFOP Enabled System Design Elements

The following paragraphs detail the considerations that went into the design and selection of products for the OA/MFOP system.

Fault Tolerance

The OA/MFOP enabled system tolerates faults by embedding (online) spare resources and employing mechanisms to control them. In the event of a component failure, the system detects the problem and reconfigures around it. The following paragraphs are specific to how this was done in the design of the Surface Ship OA/MFOP Demonstration system.

Embedded Spares

The OA/MFOP proof of concept demonstration system was configured to ensure the CNI operational capability would be available for the entire ship's deployment period of 180 days. This assumed the CNI function was needed continuously, and that the calculated probability of mission success was greater than 99%. Requirements were analyzed and allocated to a potential solution, from which a clear winner emerged. A Blade Center platform was chosen because of the inherent redundancy built into the product design. That is, the number of power, cooling, network communications, processors, and I/O elements were scalable to meet the reliability demands of the operating period.

The specific device chosen was an IBM Blade Center "T-Chassis®" as it provided comprehensive measures for component monitoring (advanced management modules), as well as extended environmental survivability, that is, TELCO hardening Standards NEBS-3/ETSA.[1] To further improve MTBF, the application server magnetic hard drives were relocated to the IBM DS3400, a highly redundant storage area network (SAN) with RAID level 6 applied.

When Reliability Block Diagrams were built to the OA/MFOP demo system configuration and analyzed (using RELIASOFT Inc., Block-Simulator 7), the built in redundancy of the system provided a greater than 99% probability of mission success. This result was expected, but what surprised the development team was that the one-year and four-year probabilities for R(t) were so high (see Figure 2).

Time	With Embedded Spares	Non Redundant
6 Month	> 99%	91%
1 Year	99%	83%
4 Years	89%	48%

Figure 2. R(t) Probability of Mission Success

[1] NEBS Level 3 Includes Specifications GR1089-Core and GR63.

This was an exciting prospect, as most Navy COTS technology Refresh Cycles occur in four-year increments. Is it possible that all spares could be installed into a system from the beginning?

Dealing With Vendor Supplied MTBF Numbers

The MTBF data provided by the vendor is not detailed enough to perform a precision analysis of failure. We transferred vendor MTBF numbers to a constant failure rate (exponential distribution), where at any time the likelihood of failure was the same. In reality, the probability for component failure is higher when a component is new, and declines to a low probability for the bulk of the hardware lifespan. The probability of component failure during this period is low and relatively stable, but failures do occur. Faults occur on a pseudo-random distribution, often referred to as the "bath-tub curve" (see Figure 3).

It should also be noted that the slope and period of these curves depend on other environmental factors, and are perturbed by temperature, humidity, vibration, and dust. The OA/MFOP demonstration system did not attempt to deal with these effects or de-rate the MTBF results to account for a shipboard environment. We dealt with this uncertainty through environmental monitoring and comparing empirical failure reports to the vendor MTBF data over the course of the system's in service life.

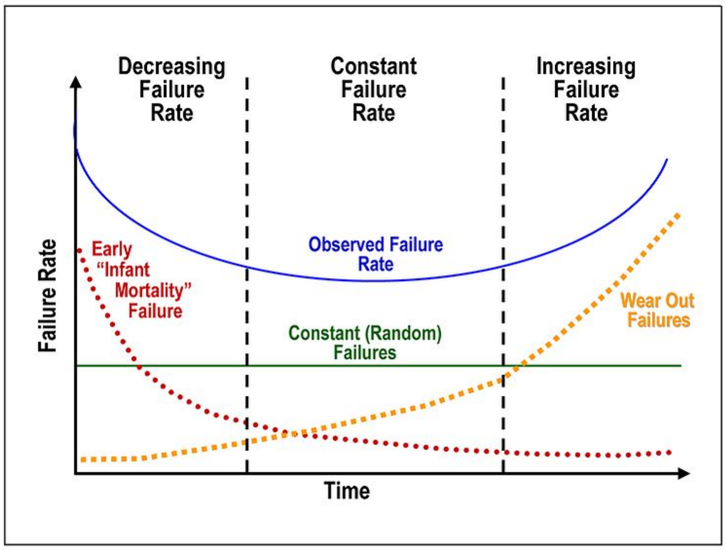

Figure 3. Computer Hardware Failure Rate Profile

Additionally, minimum thresholds for probability of mission success in the face of hardware failures can be established to initiate service technician support for the installed system. Figure 4 depicts cumulative failure density over time. The system design accounted for a number of failures to occur over the life cycle. As long as the failure rate falls below the "acceptability line," there should be sufficient hardware reliability remaining in the system to complete the stated mission time. This mission time could be stated as a deployment period (6 months), or a tech refresh cycle (4 years).

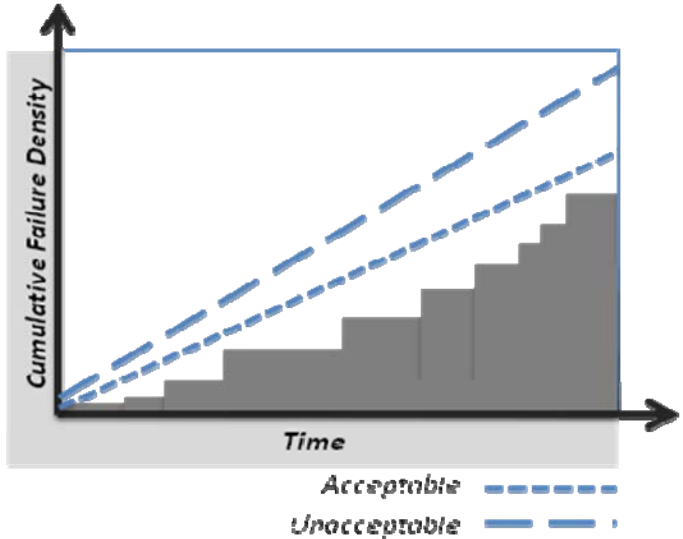

Figure 4. Repair Action Decision Criteria

Failover

Hardware redundancy is not enough. In maximizing full Operational Availability, we need to examine “Uptime” in relation to Total Mission Time. Uptime is not just the longevity of a specific piece of hardware, but the availability of the warfighting capability.

A method of automatically detecting faults and automatically responding to them was established. Processing capacity is redirected to available embedded spares (without operator intervention) in the presence of component failure. This implied that regular polling and tracking of system state information must be provided to a control mechanism that acted to restore operation according to a predefined plan. Automatically detecting faults has been a major focus of system management function effort for NSS projects in the past. Due to the development of robust data center management software capabilities in the commercial market to support innovations such as cloud computing, failover and fault recovery capability can be acquired, vice hand tooled. The OA/MFOP Demonstration development team evaluated software solutions that are commercially available to perform the basic functionality needed to sustain applications to the warfighter, maintenance free. Based on a market survey of product capabilities, the IBM Director Management Software product (Version 5.20) was chosen. This product met the requirements for monitoring and failover, but it also contained a unique feature called “open fabric manager” that managed all worldwide names (WWNs) and logical unit numbers (LUNs) for the included application servers, and could automatically reconnect the application storage volume on the SAN to a spare processor and resume processing. This greatly simplified a traditionally hard problem of reconfiguring around failures. With this method, the applications reside in the same address without any overt additional effort.

Embedded spares and failover management software are the design features that combine to represent the fault tolerant attributes of the demonstration system.

Data Capture and Collection

In the context of OA/MFOP, ongoing performance monitoring provides the feedback loop from which all management responses are applied. At the component level, messages are transmitted via Simple SNMP messages, which are trapped and processed by the system software to assist in failure response. At a higher level, this and other data is collected over time to analyze performance trends for the purposes of making proactive program support decisions. The OA/MFOP demonstration system employed a layered approach to data capture that included time series monitoring of all critical performance and environmental parameters. This layering was a critical design requirement in order to ensure scalability to multiple warfighting platforms and domains. The designers were especially concerned with the disadvantaged network user and the aperiodic communicator. MFOP performance can be achieved with small, but highly targeted system status reports to the shore-side maintainers. The crucial information made available at the appropriate time allows decision makers to perform prognostic maintenance decisions. Given that a failure has occurred, and automatic reconfiguration has been executed according to the pre-scripted recovery plan embedded in the system, a report is generated. The distance support specialist can then examine the know state of the system, the remaining hardware availability, and the likelihood of future component failures (based on life and environmental conditions), and make a decision when action is required. Three decisions are possible: (1) Near-term corrective action is necessary to sustain operational availability of the capability during the deployment period, with flyaway support personnel; (2) No action is required and corrective action can wait until after the deployment is complete; and finally, (3) No action is required until the next full Technology Insertion event. The key difference with an OA/MFOP enabled system, is that these decisions can be made throughout the lifespan of the system, and the decision criteria are fully available throughout the operational command and support infrastructure.

The Specific OA/MFOP Demonstration System Monitoring Scheme

Hardware Monitoring. All replaceable component devices in the OA/MFOP system were monitored. All components within the Blade Center hardware boundary were monitored by the two (redundant) Advanced Management Modules (AMMs). Those external to the blade center were attached to the Ethernet network, and their state data collected through SNMP and Storage Management Initiative–Specification (SMI-S) message traps. These data were then interfaced with the IBM Director Management Software for monitoring and event action response. Finally, the captured data were stored in an Oracle database that could be queried by subject-matter experts, as well as life cycle support planners, project managers, and operational commanders. This data would support those in off board analyses leading to proactive decision-making.

Environmental Monitoring. Knowing the physical environment is a key to determining cause and effect properties of the deployed hardware. Most hardware failures that occur outside the machine's expected longevity envelope are caused by extreme temperature, humidity, dust, power surges, and vibration. The OA/MFOP demonstration system included an NTI Inc. Enviromux 16™ processor to collect and transmit this data to the management server. The data were time tagged for correlation and trending purposes in support of off-board analyses.

Application Server Monitoring. There are several software agents in the market that provide various levels and degrees of application server monitoring. Generally, they all log application uptime, and provide some level of basic resource monitoring, such as CPU load percentage, Memory percentage, I/O throughput levels, and storage system utilization. The OA/MFOP system selected and used the IBM Director Management Software "Level II Managed Agent©" product for all application servers in the system.

Remote Connectivity

In order to ensure the deployed OA/MFOP system was supported while deployed, the system was connected to SIPRNET where it sent summary and event reports back to the Off Hull terminal, and if necessary, operationally restored using remote system login and administration capabilities.

Reporting

The OA/MFOP system re-used the Remote Off Hull Maintenance Support (ROHMS) software developed by NAVSEA PMS 401 contract for use in the AN/BQQ-10 sonar system to transmit status and other maintenance related reports to a connected shore side terminal. The ROHMS application is constructed on an open source software platform, including the TOMCAT™ web server and the Firefox™ web browser provided by the Mozilla™ Foundation. The ROHMS feature specifically used in the OA/MFOP demonstration was the file transfer functionality. It provided concise reports, most of which used very low network bandwidth, about the size of a typical e-mail record (2-20 KB). Reports were based on queries of specific data elements held in the OA/MFOP deployed system's database. This was not a replication server, as limiting network communication bandwidth was a priority. Under normal conditions, brief reports were sufficient. The OA/MFOP demonstration employed the following reports:

- Summary Status Report: Provided daily, it listed the status of all hardware, environmental levels, Application availability, and resource utilization.
- Event Report: On the occasion that a system event or hardware failure occurred, the ROHMS connector on the ship would transmit an Event Report, listing cause, effect, and restorative action.
- Detailed Report: A third type of report was also employed that provided event detail to be used by SMEs to determine if follow up action or planning was necessary.

Control

Distance support is an alternative maintenance concept that connects SMEs to the ship system over a network (in this case SIPRNET) to assist ship's force in restoring the tactical operation of the system. There are several techniques that can be used to assist in this manner. The two most popular are the following:

- Remote Collaboration: useful for bridging Operational to Intermediate Level maintenance; and
- Remote System Administration: used to login to a system for the purpose of restoring software operation.

The OA/MFOP system employed two Remote System Administration techniques over SIPRNET:

1. Web Browser: A menu driven login using HTTPS with Secure Socket Layer (SSL) encryption. It was used in OA/MFOP, because the system was deployed as autonomous, with no ship's force assistance. This method is very network bandwidth efficient, but in most instances, the utility provided does not necessarily require the services of an off board SME.
2. Virtual Network Connection (VNC): A technique that allows the remote SME to login to a specific server/processor at the System Administrator level. VNC

uses frame buffer relay techniques to provide the SME with a remote interface to the target machine. From there, the system can be analyzed, restored, and updated. The OA/MFOP system used the Real VNC ® product to positively control the system during deployment. All distance support objectives were accomplished without any collaboration of ship's force.

OA/MFOP Demonstration System Deployment

TEMPALT Planning and Approval

A Ship Change Document (SCD) was prepared for installation aboard USS *Iwo Jima*. The Ship Main process required that the installation package include drawings, a risk assessment, and a certified Integrated Logistics support package. These were scrutinized and approved through COMNAVSURFLANT. Since the OA/MFOP system did not require open cabinet maintenance throughout the deployment period, the certifying authority waived the following ILS products:

- Maintenance & Repair Documentation,
- 3M System Package,
- On Board Repair Parts,
- Maintenance Assist Modules,
- System Drawings,
- APL/ Supply Support Documentation, and
- Crew Training. (The crew was briefed and given the procedure for an emergency shutdown only.)

Information Assurance Challenges

In order to demonstrate Remote Connectivity capabilities, the OA/MFOP system was required to undergo Information Assurance (IA) certification by NAVNETWARCOM. An Interim Authority To Test (IATT) was sought for a six-month test period. Leading up to the OA/MFOP demonstration test date, there were no known Navy ship systems that had been granted approval to use remote connectivity for maintenance of tactical systems over SIPRNET. It is noteworthy that the ROHMS capability had been granted a one-day test on SIPRNET, but had not been approved for use on a deployed submarine. Although the data being collected over ROHMS is UNCLASSIFIED, the system application (CNI) was designed to interface to classified sensors (Link 16) and to "Text Chat" among various units of the strike group, rendering the entire system "SECRET."

Developers beware: The concept of operations (CONOPS) and bandwidth used on Navy networks is of particular importance to those who validate and approve Defense Information Assurance Information Assurance Certification And Accreditation (DIACAP) application packages. Generally, a candidate system will be required to demonstrate network communications behavior with all vulnerability patches applied. Depending on the scope and intensity of network interaction, as well as mission assurance category (MAC) level, a number of interoperability tests, conducted on a simulated tactical network will likely be necessary to gain approval of the DIACAP document. This certification is then used to request NAVNETWARCOM approval for the desired level of network connectivity, that is, Authority to Operate. Collaboration with the Echelon II IA representative should begin at least one year in advance of the accreditation need date.

The OA/MFOP demonstration project reused ROHMS and CNI from prior programs that had already undergone Navy network testing. There were sufficient elements of similarity among the systems and their interfaces to the network that OA/MFOP met the demonstration requirement “by analysis.”

Surface Ship OA/MFOP Demonstration Results

The demonstration completed in January 2011. The TEMPALT system was then removed over the last week of February 2011. Statistical performance details will be published in a report in late summer 2011. A quick-look report includes the following highlights:

- The measured operational availability of the CNI operational software was 99.67% over the deployment period. The remaining unreliability level (0.33%) was due to the two (test team) induced failures used to measure the automatic failover response of the system. The operational availability of the ROHMS application server was measured at 100%, as ROHMS was not intentionally failed while deployed.
- The physical environment was relatively benign. Temperatures hovered around 25° C, while humidity and power were stable and generally reflective of laboratory conditions.
- There were no actual hardware failures over the course of the MFOP deployment period. In fact, the system has virtually been in continuous operation for two years with no physical failures noted. This speaks to the inherent reliability of today’s Enterprise IT systems.
- Six Distance Support objectives were successfully demonstrated. These were designed to eliminate the need for shipboard ILS products, as well as Fleet Technical Assistance “Fly-Away” time and cost. These Included the following:
    - Monitoring All Hardware Status;
    - Monitoring Server Operations/ Resources;
    - Collecting System Availability and Environmental Data;
    - Remotely Inducing Simulated Failures/Observed Automatic Failover and Recovery Using Embedded Spares; and
    - Performing Remote IT, including Restarts, Pushing Files, Adding Applications, and Correcting Code Errors.

OA/MFOP in the Context of Total Ownership Cost

Operation and support costs can make up 70% of the total ownership cost of the system. A significant portion of these costs are attributable to spares, maintenance training, and their associated infrastructure. OA/MFOP targets these specific cost contributors for elimination.

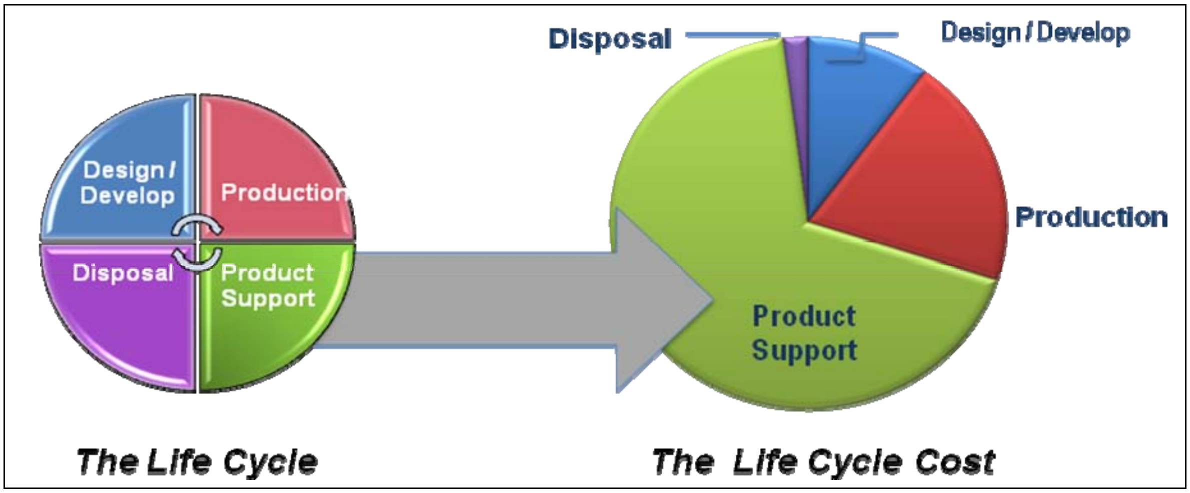

Figure 5. Impact of MFOP Design in Overall Program Costs

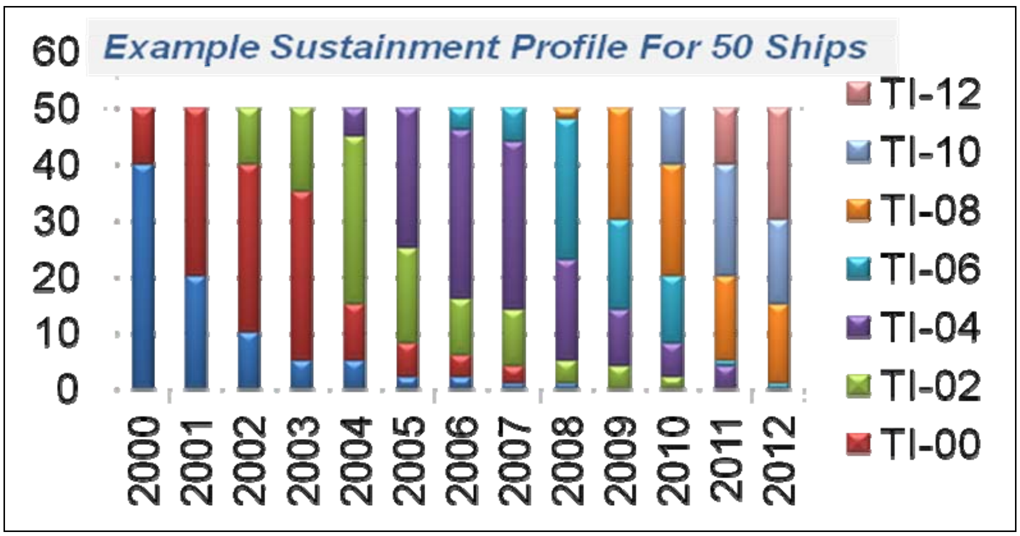

Figure 6. Impact of MFOP in Technology Insertion Life Cycle Strategy

ILS development tasks are redirected to Life Cycle Engineering purposes (Failure Modes Effects and Criticality Analysis, and the like) which feed back to System Engineering for evolutionary improvement. Thus, the modernization schedule becomes the life cycle support strategy.

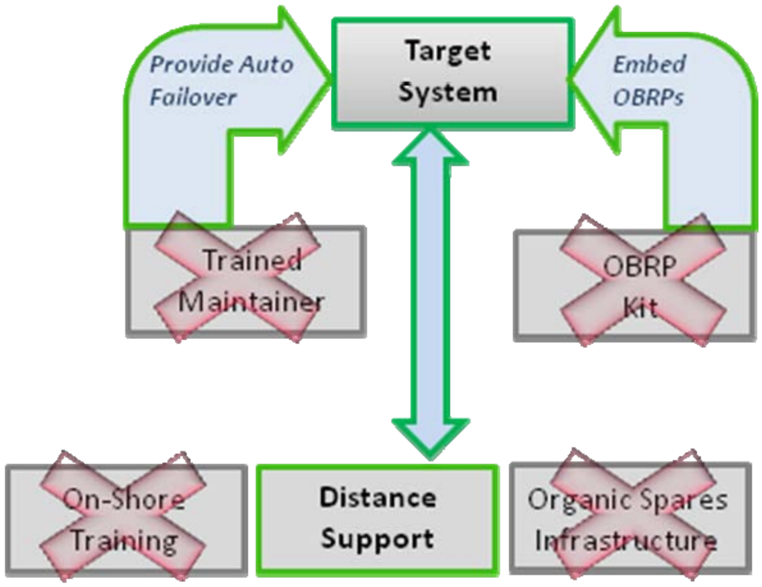

Figure 7. Cost Elements Targeted for Elimination by MFOP Design

Bounding the MFOP Environment

The OA/MFOP boundary determines the level of savings. The goal should be to include the entire system within the OA/MFOP boundary. Figure 8 shows the MFOP boundaries of the submarine sonar pilot (2005) through the surface ship demonstration (2010). Based on the market research and implementation of COTS technologies in the surface ship design, it is suggested that a majority of the Navy's tactical Information systems can implement the OA/MFOP design model across the entire system. The benefit is obvious; complete elimination of the traditional ILS support package, and the corresponding reduction in infrastructure.

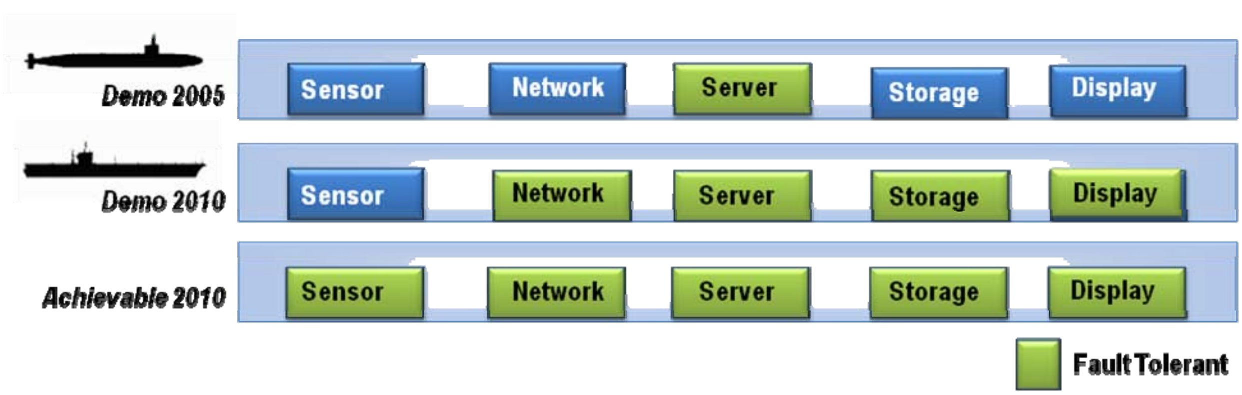

Figure 8. MFOP Boundaries Determine Level of Savings

Phased Implementation in a Strategic Stepwise Manner

Designing to an MFOP solution for sustaining capability in the field can be accomplished with low risk when starting with a new system design. However, many programs in the Navy today are doing product improvements to existing systems. For this case, MFOP capability can be achieved in a stepwise manner. We prescribe a set of steps to get the most value in the shortest time while ultimately driving to reduce shipboard maintenance to the point of elimination.

The first step is to capture the value of distance support from ship to shore through a network connection that bridges between the organic system maintainers (O) to intermediate subject-matter experts and tech assist (I) levels. This O-to-I Level Maintenance Bridge requires little product integration and will immediately generate cost savings. Table 1 highlights an example program that achieved a 15:1 cost savings ratio when employing distance support services over deploying tech assists.

Table 1. Cost Data for Fleet Technology Assistance

Fleet Tech Assist Data For Submarine Enterprise

- 120 FTA Events Performed
  - 93 Local (Norfolk)
  - 27 Out-Of-Area
- 100% Distance Support (DS) Attempts (CFFC / Command Policy)
  - 16% Success Rate Overall On All FTA Events
  - 37% Success Rate On Out-Of-Area Events
- Average MHs Per Event
  - 19 MH Via DS
  - 164 MH Via On-Site Support
- Average Cost Per Event (Based On $60.00 Per Hour)
  - $1,140.00 For DS
  - $9,840.00 Labor and $5,550.00 Travel For On-Site ($15,390.00)

15:1 Cost Savings When DS is Successful

These methods generated faster response time for solving the system problem, as well as lowering labor and travel costs. A secondary effect of preferentially using distance support vice on-site fleet tech assists is that more fleet problems per unit time can be solved by a single subject-matter expert.

The next step in this strategic path is to establish data collection in the system. The collected information can be used by the distance support elements to rapidly focus on problem areas and solve issues quickly. This will also support system health and status reporting to a variety of stakeholders, including operational commanders, so that they have up-to-date awareness on the ability for their platforms to support assigned missions. Instrumentation of system components can be quickly achieved through built in test (BiTe) and component information that is inherently available in commercial computer systems through such mechanisms as SNMP. There is a rich variety of SNMP collection agents on the market, including open source software, that provide facilities to capture data already available in any network system. Products such as ROHMS, the data collection, reduction, and dissemination utilities developed under the OA/MFOP program, have been designed to capture this data and provide reporting of system health and status information that specifically address low network bandwidth requirements.

Fault tolerant system design through built in spares and automated failover is the next of the strategic steps. This step requires a change in hardware baseline for the added resources to support failover and is the tipping point to facilitate the MFOP concept for a full deployment period. Several programs in the Navy have achieved some level of embedded redundancy and automated failover, but in the context of eliminating single points of failure, which traditionally would be immediately corrected by the O-level maintainer. MFOP designs include the elimination of single points of failure, but add the dimension of measuring the rest of the system and determining when in the future repairs need to take place in order to sustain a required probability of mission success. This is done through the development of reliability block diagrams and creating automated fault recovery routines and heuristics to sustain tactical function in the face of component failures. Prognostic maintenance decisions, vice reactive maintenance action represent the biggest shift in culture for the current fleet support environment.

The final step of reworking the life cycle planning can be quickly achieved through programmatic restructuring once the previous three technical steps are performed. When the facilities for distance support, data collection and dissemination, and fault tolerant MFOP designs are put in place, the next logical step is to retool the infrastructure to take advantage of the life cycle. This is where the fleet maintenance support infrastructure can be retooled to take full advantage of distance support and maximum elimination of open cabinet maintenance. This is also where Technology Insertion strategies can be revised to take full advantage of the MFOP concept to establish new life cycle strategies, as previously described.

How Does The Navy Drive Change?

To effectively eliminate support infrastructure, Program Sponsors must hand down strong top-level requirements (TLRs) for total ownership cost reductions to Program Managers for execution. This can be a significant challenge for a couple of reasons:

1. Modernization budgets rarely support the full range of proposed improvements, and capability enhancements are generally prioritized above those aimed at creating efficiencies in operating costs; and
2. The budget lines for O&MN infrastructure elements are carved out before the Program Sponsor level. These costs are distributed to training commands and supply chain management, and thus the acquisition offices have no insight into the potential cost savings possible with an OA/MFOP solution.

Only with full cost auditing at the highest levels of Program budget distribution can a complete cost profile be quantified.

In practice, it is common for TLRs to be collaborated on ahead of time by the Program Sponsors and Acquisition Managers (B. Johnson[2], personal communication, March 2011). (Strategies used by PMS 425 and OPNAV N87 to specify COTS requirements and methods for ARCI acquisition leading to Open Architecture implementation.) A hard operational requirement would certainly be the purview of the OPNAV Sponsor, with its technical implementation requirements left to the acquisition community. For example, if the Sponsor

[2] Bill Johnson is the inaugural program manager for A-RCI.

wants to reduce total ownership costs, the acquisition manager may offer OA/MFOP as a method of eliminating at sea maintenance cost and lowering support infrastructure. If agreed, a suitable requirement is then codified. This requirement may be transcribed as an improvement in Operational Availability, whereby the system must be restored within five minutes upon the detection and verification of a hardware failure. In practice, this requirement could only be met in a system designed to be fault tolerant. Similar requirements for maintenance data collection and distance support (over Navy networks) functionality could be specified in the solicitation (Request For Proposal) with incentives weighted toward full OA/MFOP proposals.

Commercial Trends

There are two areas where commercial IT needs are driving the development of high availability solutions: datacenter management software and redundancy/auto-recovery/failover solutions. Industry investment in cloud computing related technologies are racing ahead to support high availability solutions such as software as-a-service and virtual offices. Companies like IBM offer technologies and services under the monikers Resiliency Services, which address availability, and Recovery Services, which address failover. Both have the same purpose as, we require for an MFOP environment to protect the availability of their client's IT. The former is geared towards continuous 24X7 of the target system, while the latter maximizes the integrity of the data, with some flexibility in restoration time. The technology innovation itself is driven by large enterprise business needs for continuous data services that are secure. The business sectors driving these product development areas include the following:

1. Banking/Financial Services,
2. Distribution Centers,
3. Public Administration, and
4. Industrial.

Summary/Conclusion

The Naval Enterprise has made significant strides with Open Architecture and COTS technologies. Significant budget pressure, coupled with fleet operational demands, make it clear that we must reduce costs and increase availability using the resources we have and by combining them in new, smarter delivery packages. The techniques described in this paper, instantiated on USS *Iwo Jima*, graphically demonstrate the power and savings potential of the Maintenance Free Operating Period concept. MFOP will dramatically cut costs in training, repair, and sustainment logistics, while pushing availability to new levels of excellence. The only thing that stands in the way of an MFOP future where we purposefully reduce shipboard maintenance to the absolute minimum, thus allowing our warfighters to concentrate on fighting, is the will to require this in our systems, and grow it across the Naval Enterprise.

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